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An intelligent real-time multi-vessel collision risk assessment system from VTS view point based on fuzzy inference system

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ABSTRACT

Due to brisk industrial growth, the marine traffic has become an imperative subject in the open sea nowadays. The crew inside the vehicle traffic service (VTS) centre is facing challenging issues on account of continuous growth in vessel number. Currently, most of VTS centers' are using the ARPA RADAR based conventional vehicle traffic management system and VTS staff has to carry out most of the things manually to guide the ship's captain properly. Therefore, there is a strong impetus in the field of ocean engineering to develop a smart system which can take the data from RADAR and autonomously manipulate it, to calculate the degree of collision risk among all vessels from the VTS centre. Later on, the traffic management officer utilizes this information for intelligent decision making. In the past, several researchers have addressed this issue to facilities the VTS crew and captain of the ship but mostly, their research work was for academic purposes and could not get popularity because of extra manual workload. Our proposed vessel collision risk assessment system is an intelligent solution which is based on fuzzy inference system and has the ability to solve the said issues. We calculated the DCPA, TCPA, bearing and VCD among all vessels ships from the VTS centre by using conventional marine equipments and exploited the extracted information to calculate and display the degree of collision risk among all vessels. Furthermore, we developed the RADAR filtration algorithm which helps the VTS officer to gauge out the degree of collision risk around a particular ship. To authenticate the validity and to monitor the performance efficiency, we developed RADAR operated intelligent software which directly gets the required data from RADAR and displays the vessels list based on their degree of collision severity. The laboratory experiments confirm the validity of the proposed system.

1. Introduction and related research work

The prevention of the vessels from collisions is considered to be the main job of VTS crew. Primarily, the VTS has diverse conventional equipment such as: radar, ARPA (automatic radar plotting aid), AIS and etc. The paper (Shi & Peng, 2008) focused on ARPA equipment and highlighted the issues faced by marine engineers. The problems occurred with monitoring equipment during the last several decades caused by avoiding the human interaction and had been solved in the new approach to ARPA display with more understanding and effective interface discussed by Shi et al. These equipments are used to obtain the exact maneuvering information of vessels and to generate the anti-collision plans. On the other hand, to meet the world's growing economic needs, the shipping is increasing rapidly. Consequently, the increasing marine traffic has been emerged as an important issue. The detection of collision situations between two vessels in the VTS computing center, calculating the cost of course and speed change and automatic decision of resolving the situation was described in Chun, Qinyou, and Chaojian (2007). It's hard for the VTS operators to manage rapidly growing traffic with conventional plotting equipments and to give traffic instructions to the vessel's captain in short time. Moreover, it's nearly unfeasible to upgrade the entire VTS centre with latest automatic equipments because of their high cost. In the recent years, several researchers focused on marine system issues and tried to offer numerous solutions which could reduce the possibility of vessel collision by providing early-warning solutions. The main scope of work done by Xiaobo, Qiang, and Li (2011) was based on using ship collision risk indices to work out with the dangerous situations. One of the indexes depended on the speed of the vessel, the other – on changes of increasing and decreasing of speed and course values, and the last one – on the overlay of fuzzy domain. Kayano and Imazu (2009) built a collision avoidance support system to help the watch officer in avoiding collision at sea. The process consisted of three stages (phases): firstly, the system was preventing the officer about the risk; secondly, the safe route was chosen by the system; and finally, this better route was

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drawn on the screen. The collision algorithm, proposed by the researchers, included the step of selecting the reference points using lattice-like reference points and OZT, based on speed and route respectively (Anvar, 2003). However the best way to improve that system was to integrate an expert system into the decision process.

Later more effective collision-avoidance system was developed in Qinyou, Qiaoer, and Chaojian (2006) by utilizing legacy expert system. Qinyou et.al introduced a collision-avoidance system for vessels. In the article they described about cost model, negotiation framework along with three algorithms for reasoning mechanism and simulations. The experimental simulation of their work illustrated the interaction between two vessels which tried to get far from each other while changing their courses on the basis of collision-avoidance system. However, their work had several weak points including calculations, evaluations, and specifically in the fact that the algorithms were designed to deal with two-vessel-encounter situations. Later on a research work was carried by Perera et al. (2009a) which is regarded as a key contribution in the development of deep explanation of main COLREGs rules and regulations. The autonomous guidance and navigation (AGN) as a base for applying control engineering, and the autopilot technology were the main topics which were described; started from 1860 until present days. They categorized the navigational information into static and dynamic parts and introduced three stages of decision system for collision avoidance. The AGN has been improved by using fuzzy logic and human expert knowledge (helmsmen).

Fuzzy logic with Mamdani type rule based system was integrated; in order to detect the risk and to decide what action should be taken to avoid collision. In 2009, another research works found in the literature by Perera et al. (2009b), Perera, Carvalho, and Guedes (2011), in these articles the researchers demonstrated the collision risk assessment and decision table and Mamdani type fuzzy inference. Furthermore, they explained the angular heading and overtake situations of vessel with graphics. The researchers (Perera et al., 2009a, 2009b, 2011) utilized the MATLAB to prove the proposed scheme and displayed the results. However, one major weak point of this proposal was that if the owner vessel detects more unsuspected actions from target vessel, it's considered hard for the developed simulator to take correct decisions (Lee & Rhee, 2001; Qinyou et al., 2006). Nowadays there are lots of different ways to calculate ship collision factors at sea proposed by researchers. This field had attracted big attention from maritime authorities. The calculation of these factors was provided in YaLei, JinMin, Qing, and Fan (2011), Liu and Liu (2006), Andrzej (1999). In Andrzej (1999) the author provided a lot of equations in order to calculate the change of time and course of own vessel to avoid any crashes and called it "time to maneuver". One of the latest works was done by YaLei et al. (2011). From their point of view TCPA, DCPA and encounter angle are the main factors to avoid and prevent collision. In Liu and Liu (2006) the value of DCPA was evaluated according to the following calculation: multiple value of distance and sinus of difference between the relative course of the target vessel and bearing; whereas TCPA was equal to DCPA divide by the relative speed of the target vessel. DCPA and TCPA were used to calculate the risk degree of own vessel. In (Lee and Rhee (2001)) Lee and Rhee proposed that DCPA depends on the length of the ship, whereas TCPA depends on the speed of the vessel. It differed from the formulas described by Liu and Liu (2006). Further, collision avoidance system was developed to prove the effectiveness of the research. Primarily, they resolved the issue of accidents with more than two vessels, the action space search and expert system coupled each other to handle the complex maritime situations. Szlapczynski and Smierzchalski (2009), Mitomo, Hikida, Murai, Hayashi, and Okazaki (2008) had not restricted only for calculation of these elements while describing the visualizing collision risk process. They provided the equation through CTPA (Collision Threat Parameters Area) and DCTPA (Direct Collision Threat Parameters Area) using the Cartesian coordinate system and focusing on the safe distance between the own and several target ships.

We proposed an intelligent vessel collision risk assessment system based on fuzzy Mamdani minimum implication and it has the ability to resolve all the associated issues with marine trafficking. We introduced a novel mechanism to calculate the DCPA, TCPA, bearing and VCD between each ship from the VTS centre by using simple radar inputs. Furthermore, we utilized the extracted information to calculate and display the degree of collision risk among all ships. What's more, we developed a radar filtration algorithm which helps the VTS officer to gauge out the degree of collision risk around a particular ship. To confirm the legitimacy and to monitor the performance efficiency, we programmed radar operated intelligent software, which directly acquires the required data from radar and displays a vessels list based on their degree of collision risk severity. The rest of the article has arranged as follows: the Section 2 illustrates the proposed scheme by presenting a flow diagram. The Section 3 is about DCPA, TCPA; it provides a deep overview of the calculation procedure of DCPA and TCPA. The Section 4 deals with the bearing and variance of compass degree. It elaborates the measurement process of VCD by using simple radar inputs. The fuzzy decision table and inference methodology are discussed in Section 5 of the article. The Section 5 is designed to test the validity of the proposed scheme whereas the Section 6 is highlighting the experimental results and findings. In the last section we sum up the article by providing the future work.

2. Proposed system

We divided our proposed system in three functional layers as shown in Fig. 1. The first layer is the input layer which calculates or acquires the input parameters required for the associated modules to calculate the collision risk. We introduced a mechanism to calculate the DCPA, TCPA and VCD by using conventional VTS equipments in the first layer. The second layer (fuzzy inference layer) is the core layer of our system; it is responsible to apply fuzzy rules and to generate the intelligent decision on the behalf of this. The results of this layer are further forwarded to the display layer which is specially designed to format and present the results in human readable format. By starting the simulator, the intelligent algorithm automatically triggers the radar scanning function of intelligent algorithm. The radar scanning function inspects for all of the vessels which comes under the scanning range and stores the data in arrays and in log files for further manipulation (Yong, 2009). ARPA radar can display the information about: bearing, range, speed, CPA and etc. Since, we have been using the simple radar here which can only calculate and display limited features about marine traffic.

Initially, our program records the speed (S), angle θ of each vessel as mentioned in the algorithm Fig. 2 with ($S1, S2, S3, S4, \ldots, Sn$) $\sum_{i=1}^{n}$Si and ($\theta 1, \theta 2, \theta 3, \theta 4, \ldots, \theta$n). All the inputs which are observed at this stage would be passed to the DCPA and TCPA calculation function. Which are specifically designed to calculate the DCPA and TCPA among all the vessels through the VTS center. To increase the performance of our system, we utilized the multi-threading functionality of VC++ in our program therefore each thread represents a vessel. The usage of multi-threading not only increase the speed of final displaying due to its parallel computing logics but it can also increase the overall productivity of the software. We designed a separate thread to calculate and handle all the issues relating to the VCD (variance of compass degree).

To calculate the VCD, the bearing function first calculates the bearing by getting the inputs from radar scanning function. The intelligent VCD calculations thread handles all the matters

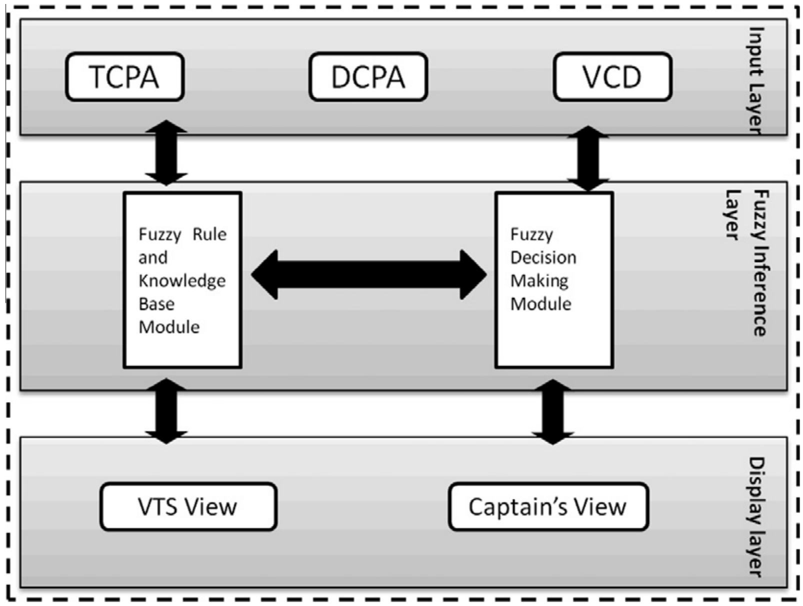

Fig. 1. Multi-vessel Collision risk assessment system architecture.

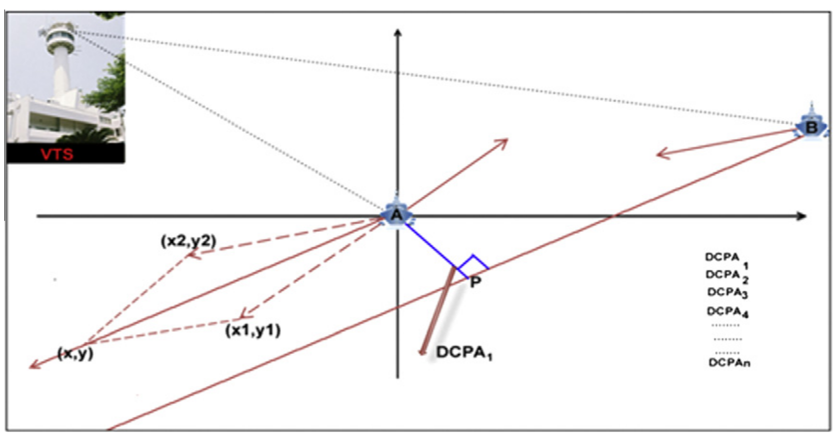

Fig. 2. Calculation of DCPA and TCPA from VTS centre.

autonomously. All the calculated inputs are finally transferred to the collision risk calculation module of the software (Yong, 2009). The risk calculation module is equipped with a fuzzy inference system which displays the calculated risk after applying the inference on values. In the following parts of the article, we elaborate each stage of the collision risk calculation steps in detail.

3. Input layer

The first layer of the proposed system is the input layer; we have integrated the input layer with VTS radar to acquire the live marine data. At initial scanning phase, we can get speed, angle and position of all vessels which come under the radar scanner ranger. The number of vessels about which we can get information is depends on the radar range. Different kinds of radars are available in the market based on the efficiency and range. In our experiments, we incorporated the conventional marine radar.

3.1. Calculation of DCPA, TCPA and VCD

To precisely measure the degree of collision risk among the vessels from VTS centre (Su, Chang, & Cheng, 2012). The Fig. 2 displays the two vessels, labeled as ship A and ship B, both the vessels are moving with different speed (S) and course (θ). The bold red arrow in the figure is indicating the distance to the closest point of approach (DCPA) between ship A and ship B. According to the Fig. 2, the direction of the vessel A is maneuvering towards the northeast while the vessel B is maneuvering towards the Southeast. For the calculation of DCPA and TCPA between vessel A and B, we can draw a projection vector in the opposite direction of the vessel A which can be examined as dotted line having geographic position points $(x1,y1)$. Similarly, for vessel B, we can draw a position vector. The Fig. 2 is displaying the projection vector for vessel B by indicating the $(x2,y2)$ as position points (Hao, Zhao, Hu, & Yang, 2007; Hogström & Ringsberg, 2012). For the sake of calculating the correlation between vessel A and vessel B, we draw a slope vector after joining the end points of both projection vectors. The figure below is clearly demonstrating the whole scenario.

Mathematically, the DCPA between vessels A and B from VTS can be calculated by using the following equations.

$$0^{\circ} < \theta < 90^{\circ}\ Then\ m = tan(90^{\circ} - \theta) \quad (1)$$

$$90^{\circ} < \theta < 180^{\circ}\ Then\ m = -tan(\theta - 90^{\circ}) \quad (2)$$

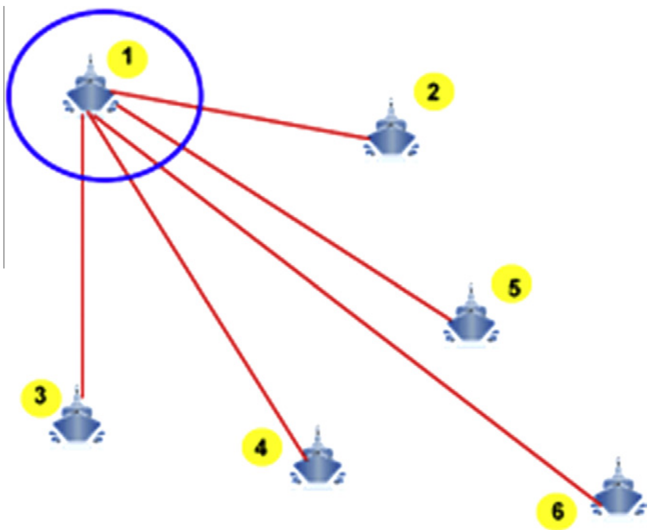

Fig. 3. Multi-Vessel DCPA, TCPA measuring scheme.

$$180^\circ < \theta < 270^\circ \; Then \; m = tan(270^\circ - \theta) \tag{3}$$

$$270^\circ < \theta < 360^\circ \; Then \; m = -tan(\theta - 270^\circ) \tag{4}$$

where θ is the angle between the vessels, calculated from the VTS centre and x, y, m is the coordinates and the slope vector respectively.

$$mx - y - mtx + ty = 0 \tag{5}$$

$$DCPA = \frac{|-mxt + yt|}{\sqrt{m^2 + (-1)^2}} \tag{6}$$

Subsequent to the DCPA calculation, we can count the TCPA which is the time to closet point of approach. According to Fig. 3, the TCPA is the time which the vessel A takes to reach the vessel B.

$$TCPA = \frac{\sqrt{(xt^2 + yt^2) - DCPA^2}}{\upsilon} \tag{7}$$

In Eq. (7), υ is the velocity while x, y and t are representing the geographic positions and time respectively (Imazu & Koyama, 1984). In order to calculate the collision risk among all ships, we have to calculate the DCPA and TCPA between each ship from the VTS centre. For example if we want to find out the risk degree associated with vessel 1 as indicated in Fig. 3 we have to calculate the DCPA among all the ships in the vicinity of the vessel. Let's suppose the scenario as presented in Fig. 3 we have six vessels and to calculate the DCPA and TCPA, we start from vessel 1 and will go to vessel six as exhibited below.

$$\text{Ship 1 case}: 1 \rightarrow 2, 1 \rightarrow 3, 1 \rightarrow 4, 1 \rightarrow 5, 1 \rightarrow 6,$$

we accommodated the three main factors of the marine maneuvering system such as: DCPA, TCPA and VCD in our approach. In this section, we elaborate the calculation procedure of these three factors

$$\text{Ship 2 case}: 2 \rightarrow 3, 2 \rightarrow 4, 2 \rightarrow 5, 2 \rightarrow 6$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$\text{Ship 6 case6} \quad \cdot \quad \cdot$$

$$\sum_{i=1}^{n} V_i \, 5 + 4 + 3 + 2 + 1 = 15$$

This was the case of collision risk assessment between the two vessels. However, for the real-time, we found hundreds of vessels under the range of VTS radar. In other words, we have to calculate the associated DCPA, TCPA among all the vessels from the VTS centre (Hara & Hammer, 1993). We performed this task by utilizing the multi-threading and iteration power of our developed software.

3.2. Calculation of VCD (Variation of a Compass Direction)

The VCD is an important factor which plays its vital role to exactly count the collision risk involved in marine systems. For the calculation of VCD, at first stage we calculate the *Bearing* among all the vessels. The *Bearing* is the angle between a line connecting two vessels and a north south-line or meridian. The *Bearing* is calculated in degree or in Mills (Zhang, Xia, & Kang, 2011). The Fig. 4 is illustrating a scenario which can help us to understand the concept of *Bearing*. The vessel A is believed to be moving in the northeast direction while the vessel B is moving towards the south-west direction of the global reference frame as displayed in Fig. 4. To measure the *Bearing* we draw a line between vessel A and B (Hao et al., 2007; Yong, 2009). If we draw a perpendicular from reference frame to vessel B, we can measure the *Bearing* by using the Pythagorean theorem. So according to Pythagorean Theorem the values ($x2-x1$) will come in base and the values ($y2-y1$) will behave as perpendicular.

$$\tan(90 - \beta) = \frac{(y_2 - y_1)}{(x_2 - x_1)} \tag{8}$$

$$(90 - \beta) = tan^{-1}\frac{(y_2 - y_1)}{(x_2 - x_1)} \tag{9}$$

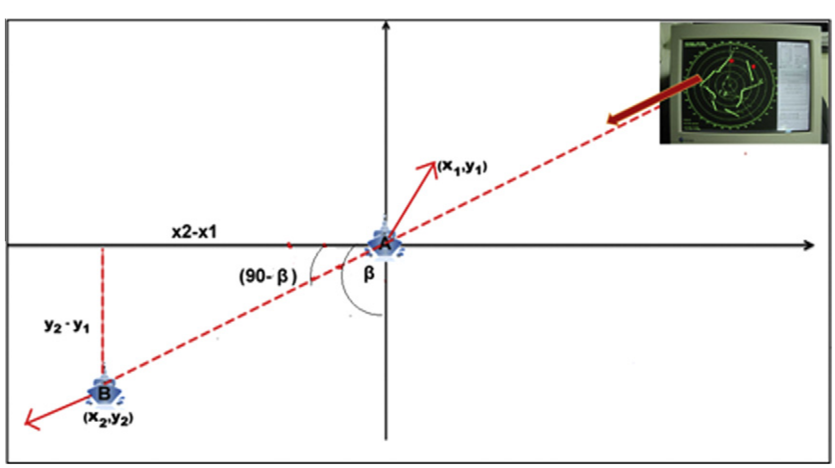

Fig. 4. Calculation of VCD among vessel from VTS centre.

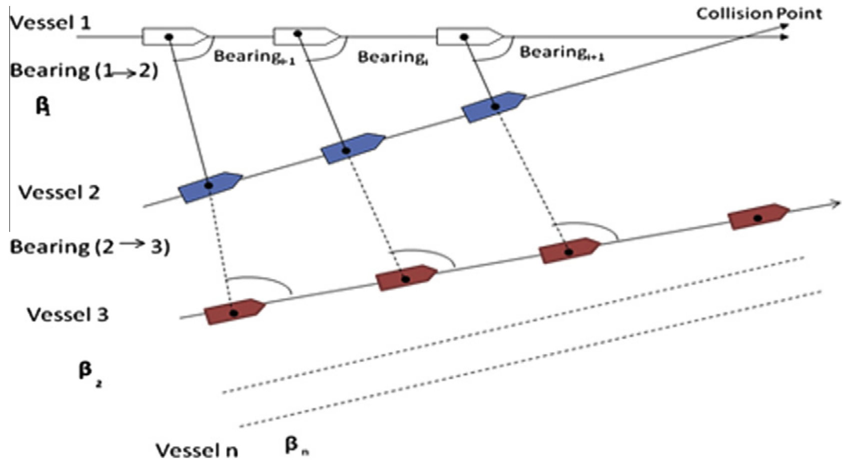

Fig. 5. Calculation of Bearing among ships.

Same like DCPA and TCPA calculation phase, at this moment we also have to calculate the VCD among the entire vessels which come in radar range.

The Fig. 5 demonstrates the VCD calculation phase graphically. The VCD is difference between two consecutive bearings regardless as it is calculated at initial phase or somewhere in the middle of the marine mission. With the help of the following equation, we can calculate the VCD among all the ships.

$$VCD = |Bearing_{i-1} - Bearing_i| \tag{10}$$

At the end of this stage, we have all the required inputs which further be used for the assessment of degree of collision risk among the vessels. To utilize the parameters parallel, we store all the inputs in separate arrays in our software. The Fig. 6 below is describing the holistic view of vessel collision calculations for better reader's understanding.

4. Fuzzy inference layer

4.1. Fuzzy set theory

Fuzzy set theory was introduced by Lotfi Zadiah in 1965 (Zadeh, 1965) to deal with vague and imprecise concepts. In classical set theory, elements either belong to a particular set or not. The concept of partial membership does not exist in classical set theory. However, in fuzzy set theory the association of an element with a particular set lies between 0 and 1; which is called its degree of association or membership degree. In our daily life, we find many vague statements like hot water, cold weather, dark night, high danger etc. We cannot quantify exactly about the severity of the danger or hotness. The fuzzy set theory adds generalization concept in classical set theory and makes it diverse enough to represent imprecise boundaries like hot, tall, low speed, high risk etc. A fuzzy set can be defined as (Yong, 2009; Zadeh, 1965).

Definition 1. A fuzzy set 'FS' over the universe of discourse 'Y' can be defined by its membership function μ_{FS} which maps element '*y*' to values between [0,1].

$$\mu_{FS} : \mathrm{Y} \rightarrow [0, 1] \tag{11}$$

Here $y \in$ Y and $\mu_{FS}\,(y)$ provides the degree of membership by which *y* belongs to Y. *y* is considered as full member of Y if $\mu_{FS}\,(y) = 1$ and, is considered as partial if $\mu_{FS}\,(y)$ is between '0' and 1 say '0.57'. If Y is continuous then *S* can be written as:

$$\check{\boldsymbol{S}} = \int_y \mu s()/y \tag{12}$$

A fuzzy set $\check{\boldsymbol{S}}$ over the universe of discourse Y is organized into ordered of set pairs:

$$\check{S} = \{(y, \mu s(\mathrm{y}))|y \in Y\} \tag{13}$$

Definition 2. Let *X* and *Y* be the two universe discourses, A fuzzy relation $R(x,y)$ is a set of product space $X * Y$ in a membership function.

$$R(x, y) = \{(x, y), \mu_{\mathrm{R}}(X, Y)|(X, Y)| \in X * Y \tag{14}$$

So in compliance with fuzzy set theory, suppose *x* and *y* are fuzzy sets in the product space $X * Y$. Fuzzy relation represents a degree of presence or absence, interaction or inter-connectedness between the elements of two crisp sets (Ahmad & Yong, 2012).

4.2. Fuzzy rule based and decision making modules

A fuzzy inference system is a popular framework which utilizes the fuzzy set theory to map the inputs to the outputs. It is a core of a fuzzy logic control system. It has been applied widely by the researchers in a variety of fields such as data classification, robotics, expert systems, pattern recognition and etc. Due to its effectiveness in multi-disciplinary fields the fuzzy inference system is known by numerous other names like fuzzy-rule-based systems, fuzzy expert systems, fuzzy modeling, fuzzy associative memory, fuzzy logic controllers, or simply (and ambiguously) fuzzy systems. If we analyze the fuzzy inference system, it can be subdivided into three main components: rule base, database or dictionary and reasoning mechanism (Jianghua & Guang, 2006). It is interesting to note that, the fuzzy inference system takes the input either in fuzzy values format or a crisp format but the output is always being in fuzzy format. So sometimes the output requires treatment before utilizing it for decision purpose, especially when we are working on a controller. We first have to defuzzify the output before its utilization. The Fig. 6 below is displaying the basic architecture of fuzzy logic based controller (Ren, Mou, Yan, & Zhang, 2011) (see Fig. 7)

The process of fuzzy inference involves all of the pieces that are described in the previous sections: Membership Functions, Logical Operations, and If-Then Rules. There are two widely used methods for fuzzy inference systems: Mamdani and Sugeno. The input for the fuzzy logic control systems is crisp data (intervals or linguistic values). The Mamdani fuzzy inference system is very popular and considered to be the first choice of controller researchers. It was

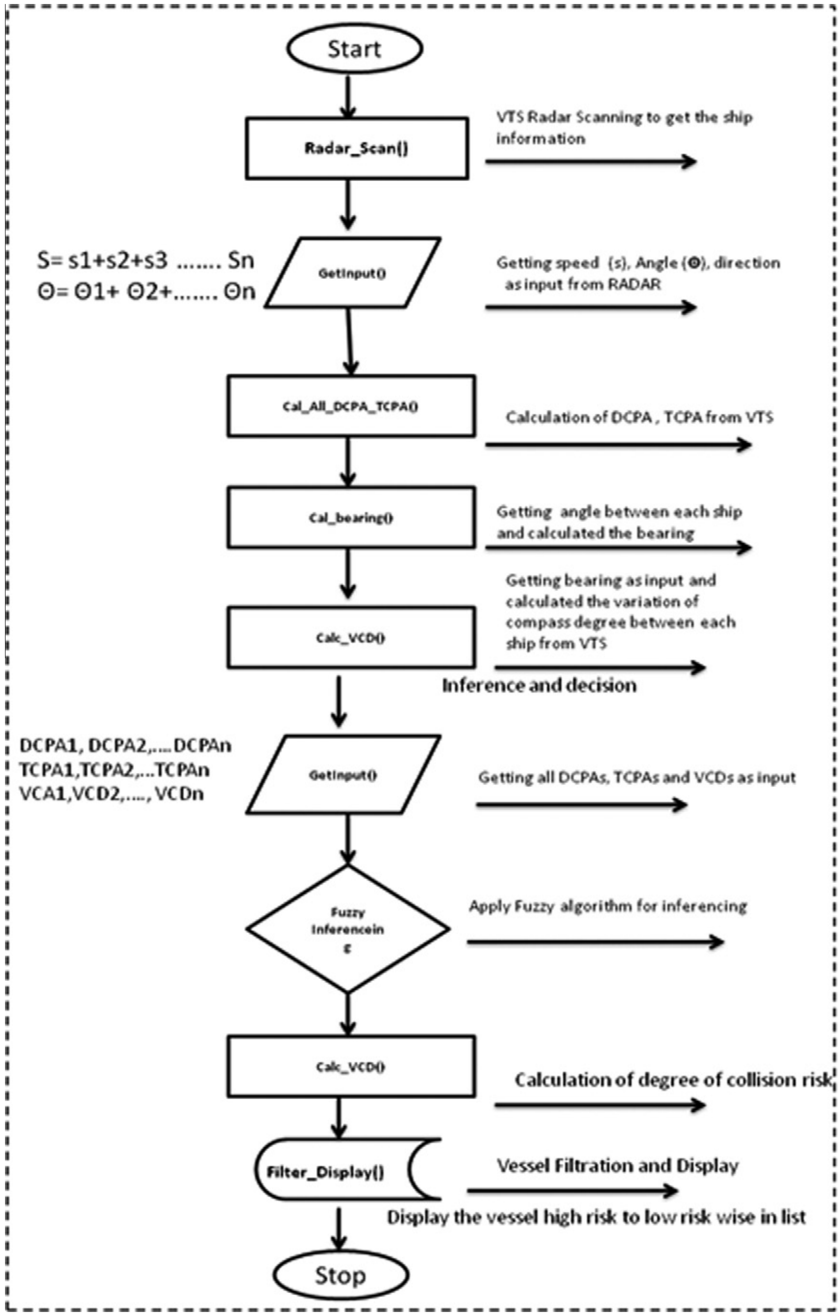

Fig. 6. Flowchart calculation of collision risk among vessel from VTS.

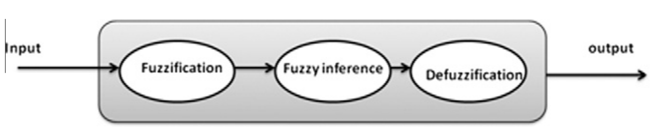

Fig. 7. A fuzzy logic Controller.

developed to control a steam engine and boiler combination of as-set of linguistic rules obtained from experienced human operators in 1977. The details of the Mamdani fuzzy inference system can be found in Mamdani and Assilian (1999). There are five kinds of defuzzification processes; among them are smallest of maximum, largest of maximum, centroid of the area, the bisector of the area and mean of maximum.

The inference module consists of basic rules like if a = max and b = max then c = max which is called Max-Criterion method. This method selects a random value from the set of maximum elements. Linguistic fuzzy model of Mamdani type is built on the fuzzy linguistic rules with linguistic variables. We formed the fuzzy reasoning rule tables to express the associated constraints with vessel collision system, later on; we generated different scenarios to validate the proposed research design and performance of the overall system (Flower & Vijeh, 1997). There are five linguistic values for the variables VCD, TCPA and DCPA (Smierzchalski & Michalewicz, 2000):

{Positive small, Positive medium small, Positive Big, Negative small, Negative medium small, Negative Big, Positive Medium Big}

The fuzzy reasoning rule tables, in case when VCD is PS, PMS, PM, PMB and PB can be expressed in the forms of Tables 1–5.

Table 1
Reasoning rule of degree of collision risk in case of VCD is PS.

		TCPA							
		NB	NM	NS	PS	PMS	PM	PMB	PB
DCPA	PS	NB	NB	NB	PM	PMS	PMS	PMS	PS
	PMD	NB	NB	NB	PMS	PMS	PMS	PS	PS
	PMD	NM	NB	NB	PMS	PMS	PS	PS	PS
	PMB	NS	NM	NB	PMS	PS	PS	PS	PS
	PB	NS	NS	NM	PS	PS	PS	PS	PS

Table 2
Reasoning rule of degree of collision risk in case of VCD is PMS.

		TCPA							
		NB	NM	NS	PS	PMS	PM	PMB	PB
DCPA	PS	NB	NB	NB	PM	PM	PMS	PMS	PS
	PMD	NM	NB	NB	PMB	PMS	PMS	PS	PS
	PMD	NS	NM	NB	PM	PMS	PS	PS	PS
	PMB	NS	NS	NM	PMS	PS	PS	PS	PS
	PB	NS	NS	NS	PS	PS	PS	PS	PS

Table 3
Reasoning rule of degree of collision risk in case of VCD is PM.

		TCPA							
		NB	NM	NS	PS	PMS	PM	PMB	PB
DCPA	PS	NB	NB	NB	PMS	PMS	PMS	PS	PS
	PMD	NB	NB	NB	PMS	PMS	PS	PS	PS
	PMD	NB	NB	NB	PMS	PS	PS	PS	PS
	PMB	NM	NB	NB	PS	PS	PS	PS	PS
	PB	NS	NM	NB	PS	PS	PS	PS	PS

Table 4
Reasoning rule of degree of collision risk in case of VCD is PMB.

		TCPA							
		NB	NM	NS	PS	PMS	PM	PMB	PB
DCPA	PS	NS	NM	NB	PB	PMB	PM	PMS	PS
	PMD	NS	NS	NM	PMB	PM	PMS	PS	PS
	PMD	NS	NS	NS	PM	PMS	PS	PS	PS
	PMB	NS	NS	NS	PMS	PS	PS	PS	PS
	PB	NS	NS	NS	PS	PS	PS	PS	PS

Table 5
Reasoning rule of degree of collision risk in case of VCD is PB.

		TCPA							
		NB	NM	NS	PS	PMS	PM	PMB	PB
DCPA	PS	NB	NB	NB	PM	PMS	PMS	PMS	PS
	PMD	NB	NB	NB	PMS	PMS	PMS	PS	PS
	PMD	NM	NB	NB	PMS	PMS	PS	PS	PS
	PMB	NS	NM	NB	PMS	PS	PS	PS	PS
	PB	NS	NS	NM	PS	PS	PS	PS	PS

The system has the type of multi-input-multi-output system; the reason is that the antecedents and consequences of rules are expressed in several linguistic variables. This kind of system includes the set of rules which has the following form:

$$R_1 : IF\, x \text{ is } A_1\, AND\, y \text{ is } B_1\, THEN\, Z \text{ is } C_1$$
$$R_2 : IF\, x \text{ is } A_2\, AND\, y \text{ is } B_2\, THEN\, Z \text{ is } C_2$$
$$R_3 : IF\, x \text{ is } A_3\, AND\, y \text{ is } B_3\, THEN\, Z \text{ is } C_3$$
. . . .
. . . .
$$R_n : IF\, x \text{ is } A_n\, AND\, y \text{ is } B_n\, THEN\, Z \text{ is } C_n$$

where x and y are the process state variables, z is the control variable, Ai, Bi and Ci are linguistic values of the linguistic variables x, y and z in the universes of discourse U, V and W, respectively.

In our case the reasoning can be expressed in linguistic rules of three-input-one-output system as:

R_1 : *if DCPA is PS and TCPA is PS and VCD isPS thenDegree of Collision Risk is PB*
R_2 : *if DCPA is PMS TCPA is PS and VCD is PS then Degree of Collision Risk is PMB*
R_3 : *if DCPA is PM and TCPA is PS and VCD is PS then Degree of Collision Risk is PM*
R_4 : *if DCPA is PMB and TCPA is PS and VCD is PS then Degree of Collision Risk is PMS*
R_5 : *if DCPA is PB and TCPA is PS and VCD is PS then Degree of Collision Risk is PSvdots* $\vdots$ $\vdots$ $\vdots$

We designed the membership functions for DCPA, TCPA, VCD and collision risk in our proposed solution. Figs. 8–10 are displaying the fuzzy membership functions graphically. Here

P: Positive	N: Negative	
S: Small	M: Medium	B: Big

5. Display layer

The display layer is the last layer of our proposed system. This layer facilitates the VTS staff to get the exact information of marine traffic and helps out to take fast and accurate decisions. Our developed system displays the output with various views. The Fig. 12

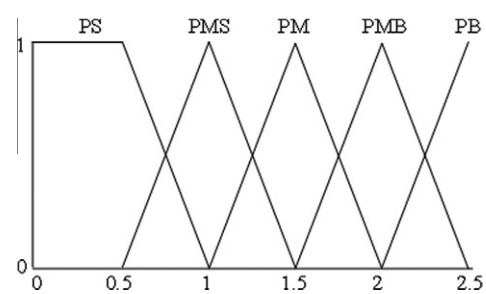

Fig. 8. Membership function of DCPA n milee).

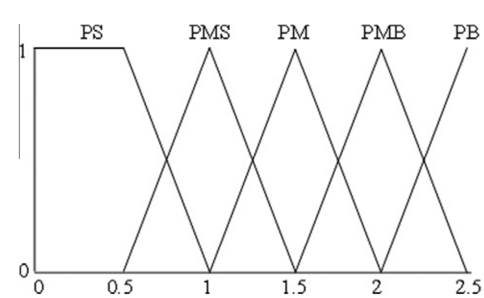

Fig. 9. Membership function of TCP (min).

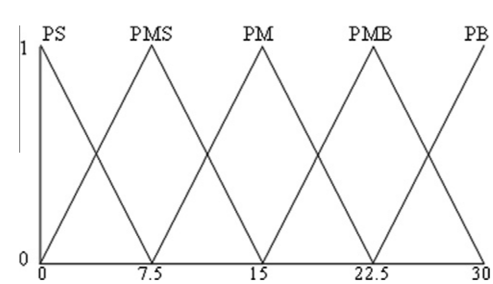

Fig. 10. Membership function of VCD.

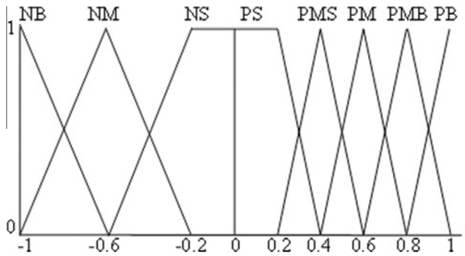

Fig. 11. Membership function of degree of collision risk.

shows the graphical user interface of the developed simulator (Okazaki, Koike, Hirai, & Kayano, 2010). We segregated the displayer layer into four sub-modules which are ship statistics module, calculation of DCPA, TCPA and VCD module, collision risk list module and filtration module as highlighted in Fig. 11. The upper left side of the simulator is describing the ship statistics module which gets the speed *s*, angle, *x* coordinate and *y* coordinate from RADAR. The drop down lists contain the entire vessel's name which comes under the range of RADAR and facilitate both the ship's captain and VTS crew to observe the desired vessels' parameters (Sui & Ren, 2006). The DCPA, TCPA and VCD calculation module which is highlighted with tag 2 manages the *x*, *y* positions of two vessels along with total speed, total angle and sum vector. The last three fields of this module exhibit the calculation of DCPA, TCPA and VCD dynamically. The module 4 displays the top 10 combination of vessels which are considered to be at high risk. The last module is the filtration module; it's particularly developed to facilitate the vessel traffic officer to take a quick decision. The user can check the associated risk of any ship by selecting a particular vessel from the dropdown menu. The central area of the prototype is the simulation area; it guides the crew of VTS centre by projecting the real-time scenario (Mitomo et al., 2008).

5.1. Experiments and results

To validate the proposed system, we developed a real-time simulator which can get the input from RADAR directly. We programmed the simulator by using the expressing power of visual C++ and for the graphical interface, further we incorporated the OpenGL library for visual interface. Our experimental environment had Intel (R) Core (TM1) 2 Quad CPU with 4.0 GB RAM, Window XP. We designed four scenarios to test the performance of the system. In scenarios, we considered that the vessels are moving with 20 Knot speed while we kept the courses as varied and changed in each scenario to closely monitor the differences among DCPAs and TCPAs. We recorded the results of each scenario by using our proposed system and compared these with the existed techniques at the end of the experiments. Since in the old schemes, they just calculated the collision risk by using two vessels so we also used two vessels scenario for better comparison. The Tables 6–9 are displaying the comparative results.

Table 6
Navigation condition of scenario.

Scenario no.	Own vessel course (°)	Opposite course (°)
1	10	165.4 + 0.3
2	50	130 − 1
3	60	45
4	315	135

Table 7
Degree of collision risk of scenario 1.

No	DCPA	TCPA	VCD	Proposed scheme	Existed technique
1	0.16	0.10			
2	0.15	0.09	0.45	0.89	1.00
3	0.14	0.07	0.63	0.85	1.00
4	0.14	0.05	0.98	0.77	1.00
5	0.14	0.04	1.82	0.62	1.00
6	0.13	0.02	4.85	0.46	1.00
7	0.13	0.00	47.32	0.40	1.00
8	0.14	−0.01	41.45	−1.00	−1.00
9	0.14	−0.03	7.08	−0.05	−1.00
10	0.14	−0.05	2.24	−0.69	−0.98
11	0.15	−0.06	1.13	−0.84	−0.98
12	0.16	−0.08	0.70	−0.90	−0.98
13	0.17	−0.10	0.48	−0.92	−0.98
14	0.18	−0.11	0.37	−0.94	−0.98
15	0.19	−0.13	0.29	−0.95	−0.96
16	0.21	−0.15	0.24	−0.95	−0.96
17	0.23	−0.16	0.21	−0.95	−0.96
18	0.24	−0.18	0.18	−0.95	−0.96
19	0.26	−0.20	0.17	−0.95	−0.96
20	0.29	−0.21	0.15	−0.95	−0.94

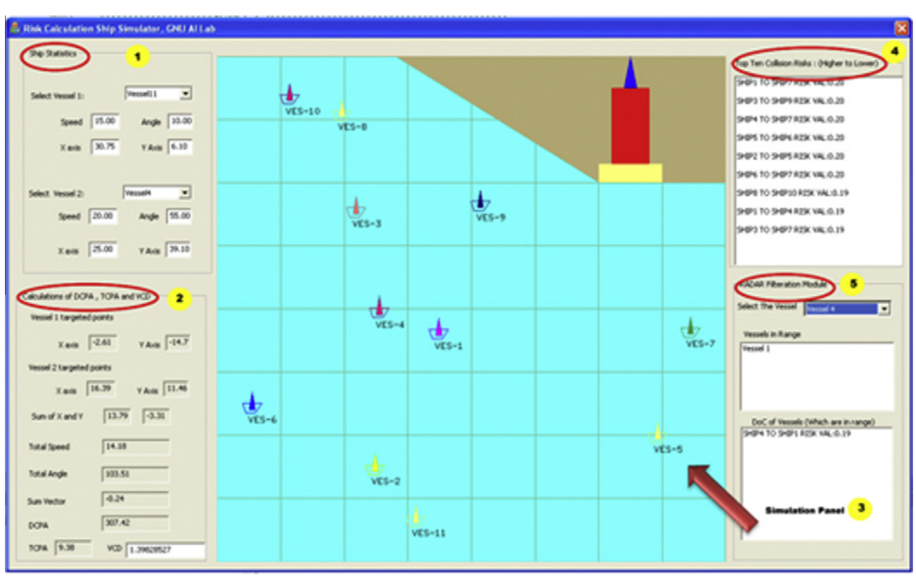

Fig. 12. Screenshot of the vessels collision assessment simulator.

Table 8
Degree of collision risk of scenario 2.

No.	DCPA	TCPA	VCD	Proposed scheme	Existing scheme
1	0	0			
2	0.33	1.05	0	1	1
3	0.46	0.01	0.03	1	1
4	0.67	0.97	0.05	0.53	0.54
5	0.87	0.93	0.09	0.50	0.50
6	1.06	0.89	0.12	0.64	0.8
7	1.23	0.85	0.17	0.36	0.46
8	1.40	0.81	0.22	0.42	0.55
9	1.56	0.77	0.27	0.47	0.47
10	1.71	0.73	0.34	0.27	0.28
11	1.84	0.68	0.43	0.25	0.25
12	1.97	0.64	0.52	0.35	0.36
13	2.09	0.60	0.65	0.28	0.28
14	2.19	0.55	0.8	0.18	0.18
15	2.29	0.51	0.99	0.14	0.14
16	2.38	0.46	1.23	0.14	0.14
17	2.46	0.42	1.55	0.15	0.17
18	2.52	0.37	1.97	0.15	0.2
19	2.58	0.33	2.55	0.13	0.2
20	2.63	0.28	3.37	0.11	0.2
21	2.67	0.23	4.56	0.08	0.2
22	2.70	0.18	6.32	0.03	0.2
23	2.73	0.14	8.96	0.16	0.2
24	2.74	0.09	12.68	0.06	0.2
25	2.75	0.03	16.91	0.15	0.2
26	2.74	0.02	19.32	0.08	0.2
27	2.73	−0.07	17.70	−0.21	0
28	2.72	−0.12	13.66	−0.04	0
29	2.69	−0.18	9.72	−0.06	0
30	2.65	−0.23	6.85	−0.02	−0.01
31	2.61	−0.29	4.92	−0.07	−0.01
32	2.56	−0.35	3.62	−0.10	−0.01

Table 9
Degree of collision risk of scenario 3.

No.	DCPA	TCPA	VCD	Proposed scheme	Existed scheme
1	0.63	0.58			
2	0.63	0.53	0.38	0.59	0.59
3	0.63	0.48	0.46	0.59	0.59
4	0.63	0.43	0.56	0.59	0.59
5	0.63	0.38	0.71	0.59	0.59
6	0.63	0.33	0.92	0.59	0.59
7	0.63	0.28	1.24	0.59	0.59
8	0.63	0.23	1.76	0.59	0.59
9	0.63	0.18	2.68	0.52	0.59
10	0.63	0.13	4.56	0.32	0.59
11	0.63	0.08	9.25	0.48	0.59
12	0.63	0.03	25.04	0.31	0.59
13	0.63	−0.02	299.1	0.00	−0.44
14	0.63	−0.07	35.85	−0.01	−0.40
15	0.63	−0.12	12.15	−0.01	−0.40
16	0.63	−0.17	5.56	−0.01	−0.39
17	0.63	−0.22	3.12	−0.02	−0.40
18	0.63	−0.27	1.99	−0.02	−0.40
19	0.63	−0.32	1.37	−0.02	−0.42
20	0.63	−0.37	1.00	−0.03	−0.46

5.1.1. Scenario 1

In scenario 1, both vessels are moving 20 knots/mile and we set 10° course for own vessel and 165.7° course for opposite while the starting points of both vessels are different. It can be seen in Fig. 13 that the ships are colliding near the center of their journey. We performed the simulation and recorded the results in Table 6 (see Figs. 14–16)

5.1.2. Scenario 2

In the second scenario, we changed the courses of own and opposite vessels from previous degree to 130° and performed the experiments. The experiment results can be observed in Table 7. The purpose behind the repetition of experiments by changing the course is to deeply analyze the efficiency of the algorithm and observe the overall impact on decision making.

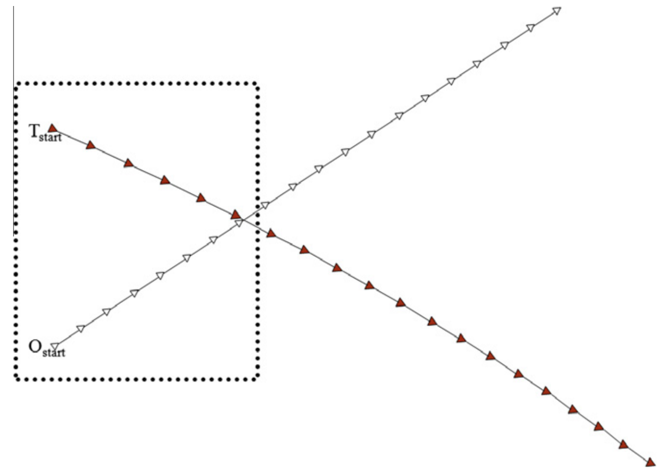

Fig. 13. Navigation route of scenario 1.

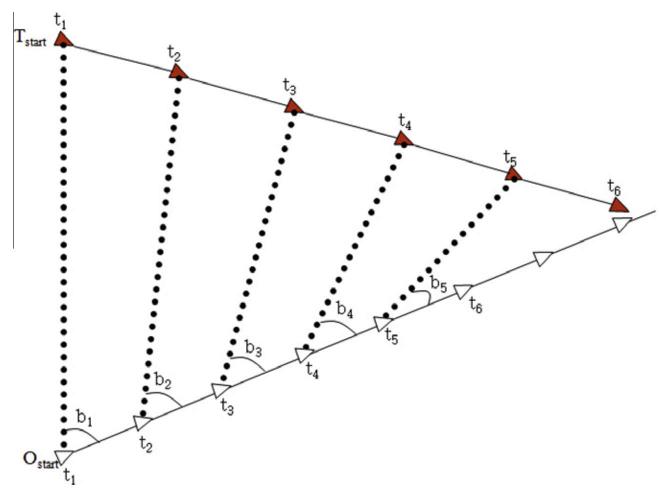

Fig. 14. An enlarged figure of scenario 1.

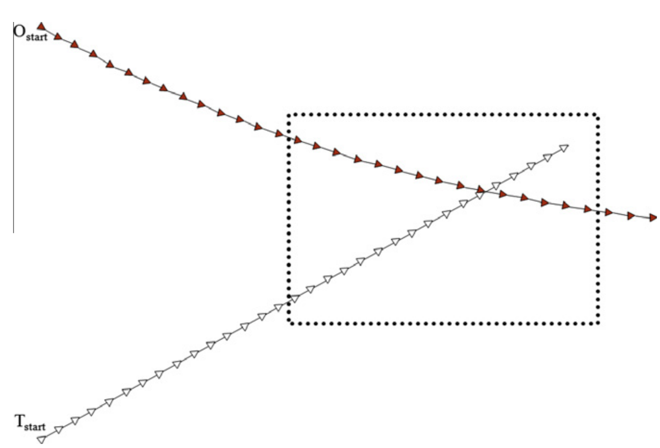

Fig. 15. Navigation route of scenario 2.

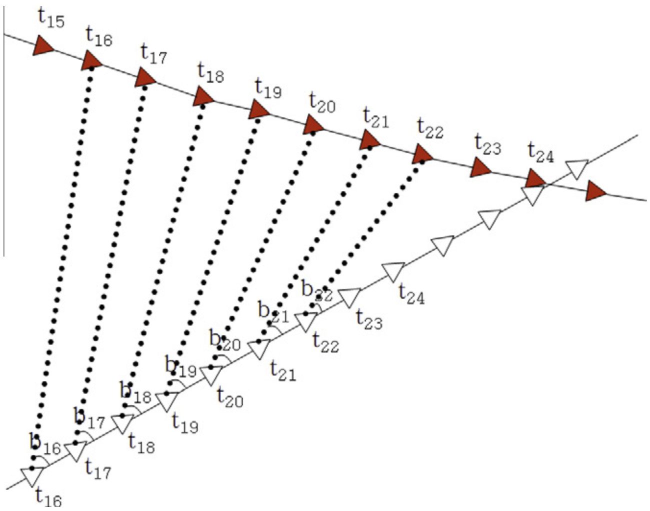

Fig. 16. An enlarged figure of scenario 2.

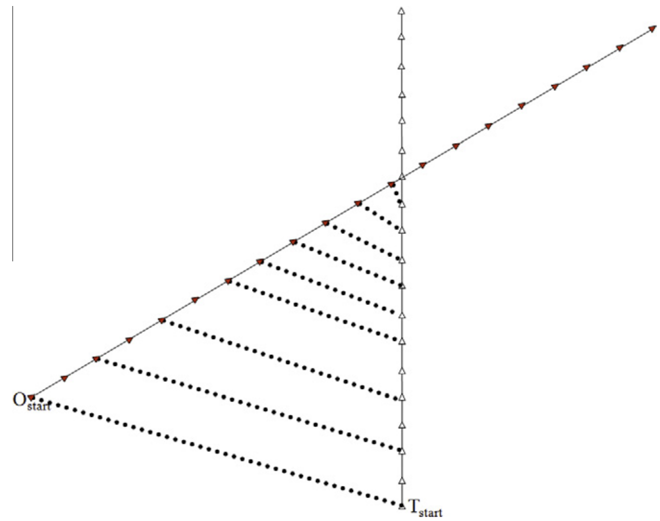

Fig. 17. Navigation route of scenario 3.

Table 10
Degree of collision risk of scenario 4.

No.	DCPA	TCPA	VCD	Proposed scheme	Existing scheme
1	1.41	0.32			
2	1.41	0.27	1.17	0.44	0.44
3	1.41	0.22	1.69	0.41	0.44
4	1.41	0.17	2.67	0.33	0.44
5	1.41	0.12	4.78	0.33	0.44
6	1.41	0.07	10.76	0.31	0.44
7	1.41	−0.02	35.33	0	−0.42
8	1.41	−0.03	69.24	0	−0.42
9	1.41	−0.08	24.62	−0.01	−0.49
10	1.41	−0.13	8.36	−0.10	−0.49
11	1.41	−0.18	4.01	−0.15	−0.49
12	1.41	−0.23	2.33	−0.13	−0.48
13	1.41	−0.28	1.52	−0.13	−0.48
14	1.41	−0.33	1.07	−0.10	−0.48
15	1.41	−0.38	0.79	−0.06	−0.47
16	1.41	−0.43	0.61	−0.05	−0.47
17	1.41	−0.48	0.48	−0.04	−0.47
18	1.41	−0.53	0.39	−0.03	−0.46
19	1.41	−0.58	0.33	−0.03	−0.46
20	1.41	−0.63	0.27	−0.02	−0.46

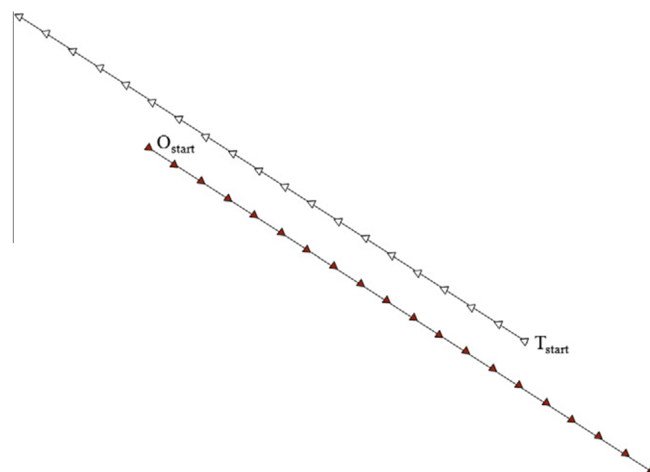

Fig. 18. Navigation route of scenario 4.

Table 11
Proposed and existing system accuracy comparison.

Scenarios	Proposed scheme accuracy (%)	Existing scheme accuracy
S1	95.78	79.5
S2	98.8	83.36
S3	96.46	86.95
S4	92.9	72.6

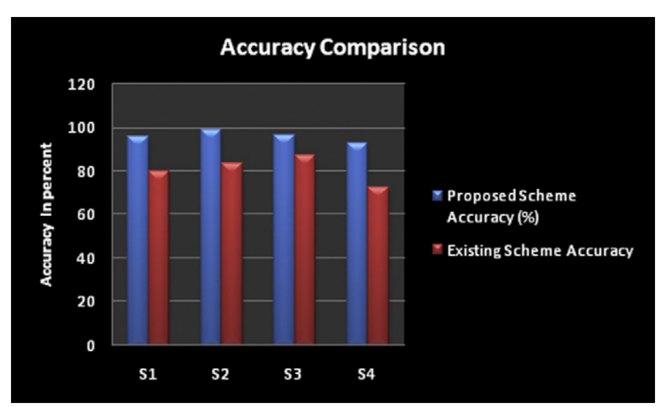

Fig. 19. A Graphical view of accuracy performance.

5.1.3. Scenario 3

In the third scenario, we tuned the angles again and at this time set 60° for own and 45° for the opposite vessel. The Table 9 is depicting the gathered results.

5.1.4. Scenario 4

For the scenario 4, we gave an extreme shift in the angle and set 315° and 135° for own and opposite vessels respectively. The results observed in this scenario are calculated in the form of Table 10.

After performing all the experiments, we derived an accuracy report to analyze the level of improvement between our proposed and existing technique. The results of this report can be viewed in Table 11. It is pretty clear from Fig. 17 that we can achieve significant improvement in vessel collision assessment by utilizing the proposed scheme (see Figs. 18 and 19).

6. Conclusion

In this article, we worked out to facilitate the VTS crew members by making the process of collision risk assessment automatic. We introduced a dynamic methodology of calculating the DCPA, TCPA and Bearing by using the VTS radar input directly. As mentioned in the related work portion, none of the systems which were developed so far are able to calculate the degree of collision risks from VTS centers using conventional equipments. The technique which we introduced not only fills the said technology gap but can also provide an efficient and economical solution for remote monitoring. We developed a simulator which completely automates the laborious process of manual assessment. We keenly analyzed and compared the results gathered by using our developed simulator with the previous systems results. The results are extremely satisfactory and validate the authenticity of our proposed system. On the other hand, we are facing some challenging issues relating to radar data which is generated sometimes noisy and incomplete. We are trying to overcome all the associated issues related to risk calculation by using our proposed scheme. Until this, we are confident enough to say that our technique can manage the marine traffic excellently.

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